

# Towards New Modes of Collective Musical Expression through Audio Augmented Reality

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## ABSTRACT

We investigate how *audio augmented reality* can engender new collective modes of musical expression in the context of a sound art installation, *Listening Mirrors*, exploring the creation of interactive sound environments for musicians and non-musicians alike. *Listening Mirrors* is designed to incorporate physical objects and computational systems for altering the acoustic environment, to enhance collective listening and challenge traditional musician-instrument performance. At a formative stage in exploring audio AR technology, we conducted an audience experience study investigating questions around the potential of audio AR in creating sound installation environments for collective musical expression.

We collected interview evidence about the participants' experience and analysed the data with using a grounded theory approach. The results demonstrated that the technology has the potential to create immersive spaces where an audience can feel safe to experiment musically, and showed how AR can intervene in sound perception to *instrumentalise* an environment. The results also revealed caveats about the use of audio AR, mainly centred on social inhibition and seamlessness of experience, and finding a balance between mediated worlds to create space for interplay between the two.

## Author Keywords

augmented reality, sound art installation, collective musical expression, mobile music making

## CCS Concepts

•Applied computing → Media arts; •Human-centered computing → User studies; Mixed / augmented reality;

## 1. AUGMENTED REALITY INSTRUMENTS

Designers of new musical instruments typically focus on material interfaces, mappings, and sound generators to create new modes of musical expression. A further way to intervene in the process of music making is to directly alter the player's perception of an instrument through digital augmentation of the senses. We define *audio augmented reality* as realtime computational mediation of sound perception,

mixing live digitally processed sound with real environmental sound, and investigate how this can engender new modes of musical expression. This investigation forms part of an ongoing sound art installation project, exploring the creation of environments for collective musical expression incorporating augmented reality (AR), for musicians and non-musicians alike.

In the last few years there has been a resurgence of interest in AR with the introduction of widely accessible new interfaces (e.g. mobile phones, Microsoft HoloLens [19], *hearables*) and new applications [15]. Azuma's [2] original discussion of AR took a multisensory perspective (e.g. visual, audio, haptic), although artists and technologists have primarily explored this medium in the visual domain [1] by layering graphics over realtime environments, as found for example in Shaw's early work [10]. Within NIME, research that defines itself as AR has primarily been focused on visual augmentations for technology-assisted learning [12, 9]. There has also been extensive work on augmenting the sense of touch (e.g. [17, 11]), which could inform future AR applications.

A key development in the field of audio AR has been apps such as RJDJ [5], which use mobile phones with connected headphones as a platform to reprocess the sound environment, creating new listening experiences. We use similar technology to RJDJ to examine the aesthetics of collective musical expression at the intersections between collective mobile instruments (e.g. [16]), sound art installations and audio AR.

At the core of this research we question *how can audio augmented reality enable collective musical expression?* Consequently leading us to ask: how does musical experience become *collective* within a sound art installation environment? How are different communication channels used?

We examine these questions in an audience experience study. This study took place at a formative time in the development of our installation, as a way of exploring the sound art aesthetics of AR and the contribution they will make to the final design.

## 2. DESIGN TOWARDS INSTRUMENTNESS

The sound art installation is designed as a composed acoustic environment towards playfulness for both musicians and non-musicians. It brings together audio AR and acoustic reflectors with the aim to alter the installation space towards instrumentness by mediating the audience sound perception and hearing experience. *Instrumentness* is seen here as the way in which a musical instrument is controlled and conceptualised as a medium for creative action (e.g. virtuosity, playability)[4], as a feedback loop between interface, software and audience creative expression. In this sound art installation, the feedback loop is situated between the app and peripherals, the acoustic reflector and the audience.



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## 2.1 App and peripherals

An iOS app was built using OpenFrameworks. It hosted a PureData patch, using LibPD[6], enabling processing of the phone microphone signal, which was played back through bone-conduction headphones. Two variants of the app were built with different signal processing configurations, each one designed to alter the natural balance of environmental sound so as to change perception of interpersonal space; bringing the audience closer to each other. The first (figure 1) used heavy compression of upper-mid frequencies to emphasize the breath and bodily sounds. The second (figure 2) expanded on this patch, additionally altering spatial qualities by presenting different band-pass filtered reverbs in each ear. Here the audience's own movements and vocals were amplified. Audience members were given the app

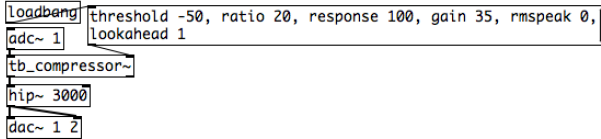


Figure 1: Patch 1

with a mobile phone (which they were free to hold in ways they saw fitted best) and a pair of bone-conduction headphones<sup>1</sup> [14]. These headphones transmit sound directly to the cochlear, bypassing the outer ear and ear drum, and so do not intervene in natural hearing. This allows our system to mediate the sonic environment by creating a mix of the real sound environment and digital reprocessing of the same environment, collected through the phone microphone. It also allows the audience to interact with each other while they experience the merging of real and digital environments. This system aims to fulfil our definition

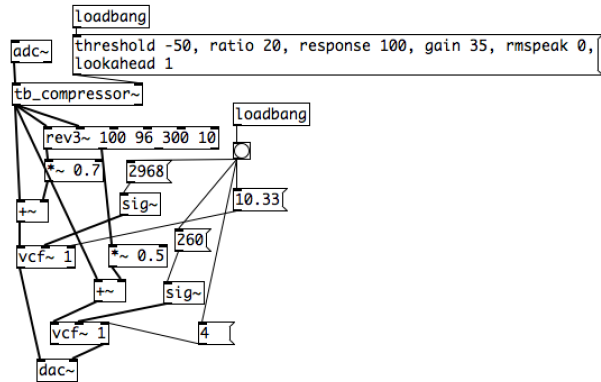


Figure 2: Patch 2

of audio AR as realtime computational mediation of sound perception, mixing live digitally processed environmental sound with the real sound of the environment.

## 2.2 Acoustic Reflectors

In wanting to control the acoustic environment to create a deeper sense of hearing/listening for the audience members, the design was initially inspired by wartime sound mirrors [8], the Tvísöngur sound sculpture[13], *Unplugged Kingsize Megaphones*[7], and the design of *Inside the Hearing Machine*[3]. Each of these sound sculptures or artefact amplifies its own environment resonance through the use of a parabolic shape. Parabolic shapes with  $l/a = 4$  [20] have been established as the most efficient dimensions for the structure to become an optimal sound reflector. With this in mind, and to maximize the parabolic resonance, the

parabola was built from aluminium metal sheets, 16 x 1 meter long piano wires and polymorph. Both wood and tin metal had been used in previous non-electronic resonators for similar reasons [3]. Each metal sheet was cut broadly following a parabolic design for DIY solar reflectors [21] and tied up and brought under tension with 401 copper threads, bending each piano wire and aluminium sheet to form the parabolic shape (see figure 3). Two further acoustic reflectors were used in the installation, a 1m x 0.5m semicircular reflector made from framed sheet aluminium, and an 80cm diameter ceiling hung plastic parabolic reflector taken from a *sound dome*.

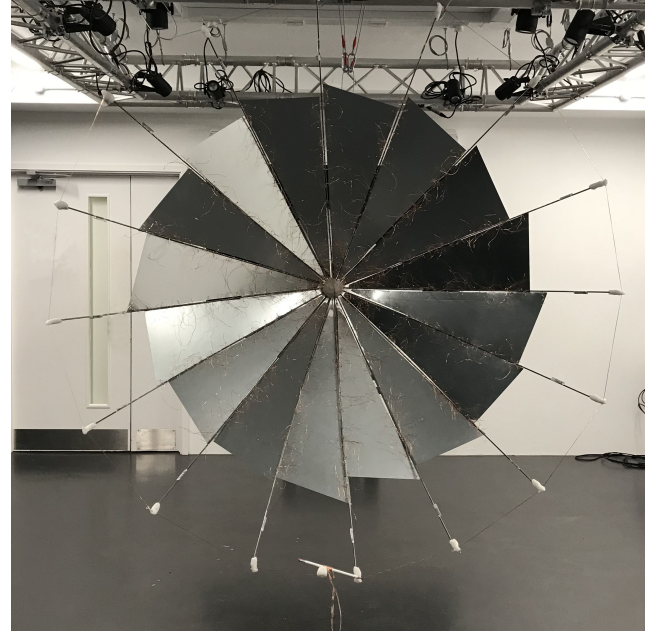


Figure 3: Acoustic Reflector

## 2.3 Feedback loop design

In composing the acoustic environment, two sound sources were being mediated by the app, its peripherals and the acoustic reflectors (see figure 4): (i) the airborne sound (from the reflectors and audience's own vocal sounds), (ii) structure-borne sonic vibrations (from the bone-conduction headphones and the reflectors).

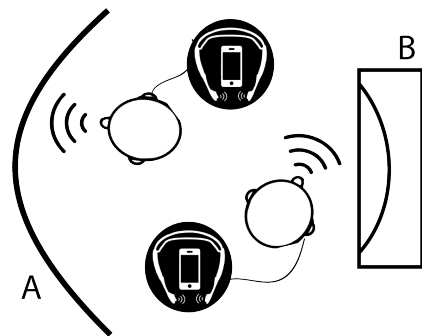


Figure 4: Feedback Loop. A and B are acoustic reflectors

## 3. AUDIENCE STUDY

The study was designed to provide formative feedback on the use of audio AR as a core part of a sound art installation. It was intended as a means to locate key concepts that

<sup>1</sup><https://aftershokz.co.uk/>

will frame ongoing development of the piece. We set-up a testing environment in an empty room using three types of parabolic sound reflector, and two versions of the audio AR app, and asked small groups of participants to explore it freely.

## 3.1 Method

The study was structured in 3 parts: (i) initial basic instructions (5 minutes) were offered to participants to become familiarised with the bone-conducting headphones, as well as how to navigate between the two mobile applications; (ii) 4 groups of 2-3 participants engaging with the spatial physical and digital instrument with limited instruction (10-30 minutes); (iii) group interviews (30 minutes) that were designed to address the user/audience experience in terms of their own experience as a whole, in terms of seamlessness between the mixed realities and in terms of playfulness and engagement with the installation.

The 4 groups were randomly organised. 9 participants took part in the study, aged between 26 to 55 (mean: 43) with 4 female and 5 male. 6 identified as practising artists. 8 had received formal musical training, ranging from 4 years to lifetime. 7 participants considered themselves to be actively engaged with arts events. One participant had previous experience of bone-conduction headphones.

Four group-interviews were recorded, transcribed and analysed using a grounded theory approach [18], by two researchers in collaboration. The transcriptions were coded; these codes were grouped into concepts, and then into broader categories.

## 3.2 Results

The grounded theory analysis resulted in three categories: 'audio augmented reality experience', 'instrumentness' and 'collectiveness'.

### 3.2.1 Audio Augmented Reality Experience

Discussions fell into concepts around seamlessness, immersion and boundaries. Comments concerning immersion (i.e. the sense of *being* in the installation environment) all centred around experience of the mobile software. Participants talked of a striking difference when the app was switched off<sup>2</sup>. Some participants felt a deep sense of immersion within the environment<sup>3</sup>. One participant felt the app interrupted the sense of immersion<sup>4</sup>, and another talked of exploring the augmentations rather than accepting them<sup>5</sup>. There were mixed opinions about the seamlessness of the bone-conducting headphones, ranging from them feeling unnatural to very natural<sup>6</sup>, or in-between<sup>7</sup>.

<sup>2</sup>"it was quite a shock when i turned the app off", "it was quite striking that when you took the headphones off, it suddenly seemed really boring ... it suddenly seemed very different"

<sup>3</sup>"it felt immersive in the sense that it's part of my physiology", "[the app] felt immersive, it did give that sense of being in an interesting little world", "everything felt like it had deep significance", "that feeling when i turned off the reverb, one of slight disappointment", "...felt like I was in a film"

<sup>4</sup>"the thing became the instrument, which is unfortunate because it kind of separates out that sense of immersion"

<sup>5</sup>"when you're in a space that you're unfamiliar with, it always seems like you're trying to work out what the parameters of that augmentation are, rather than accepting that augmentation rather than a world that you already kind of have a perception of"

<sup>6</sup>"once you get into it, I totally forgot I had something on my ears ... I think at the end it was very natural"

<sup>7</sup>"it wasn't quite natural but it was going that way"

### 3.2.2 Instrumentness

The piece enabled various forms of playful approaches to exploration of the environment<sup>8</sup>. Asked "when does a space become instrumental to you?", participants replied "when it gives things back... I felt like I was getting a lot back from the imaginary space" and "when you can learn from it". Several participants felt that the experience of the software overrode the experience of the physically constructed environment<sup>9</sup>.

### 3.2.3 Collectiveness

Responses in this category centred on how collective interactions in the installation worked well, and where difficulties lay. Participants reported feeling comfortable and safe<sup>10</sup>. This was attributed to the feeling "enclosed in this sound world" and "hearing [sounds] in this wonderful electronic haze", and feeling encouraged by other audience members<sup>11</sup>. Difficulties arose from social inhibition in openly creating sound within the installation environment<sup>12</sup>. Further discussion focused on ambiguity of sound sources within the environment, with difficulty in determining who was making a sound, or whether it was synthetic<sup>13</sup>.

## 4. DISCUSSION

The results highlighted some differences in opinion between participants, firstly about inhibition and experimentation; while some felt safe and comfortable to experiment within the installation environment, others felt more reserved. Speculatively, this may have been connected with the particular mix of the groups, as some groups were more performative than others, or developed a desire to hear each other collectively within the audio AR environment. It also needs to be noted that a few participants pointed out how the sensation of feeling safe was linked to the immersive experience in the audio AR environment.

There were some mixed opinions about the seamlessness of the bone conduction headphones. It may be possible to improve the experience of these by giving each participant a mobile phone holder to free their hands to adjust the headphones for a comfortable fit. One of the main successes was the degree of immersion the participants reported, with several participants describing a feeling of shock or disappointment when the headphones were removed and they left the AR environment. There were also comments about ambiguity of whether sounds sources originated in the real or AR environment, again demonstrating a high degree of immersion. Success in this area however contributed to difficulties in balance between the AR and constructed physical environment, and highlights the compositional challenge of

<sup>8</sup>"it was fun to try different sounds and see how they reacted to the environment and the sonics effects, to decide which ones were the best", "I got interested in banging the phone about to get feedback, and I tried it with the acoustic reflectors", "I found it quite fun just flicking the end of the headphone connector ... as an impulse"

<sup>9</sup>"because the electronic soundscape is so strong, I'm very much less aware of the real space", "with the app you don't get to see the magic of this [object]"

<sup>10</sup>"when I put the app on, it was such a contrast and, not being a vocalist of any kind, it was very exciting because it felt safe to make sounds of any kind, even though we were present in the room, and I found that very exciting"

<sup>11</sup>"but when there are other people around, somehow the fact that it sounded great to me, individually, is making me braver in what I would do vocally"

<sup>12</sup>"I have an inhibition about making strange purposeless noises"

<sup>13</sup>"you might not know if you were interacting with what was in front of you, or a person"

creating an interplay between acoustic and digital aesthetics without over-dominance of the AR system.

A key aim of the sound installation design was to invite play, to create a musical environment physically and virtually. In the study, this occurred in unexpected ways. The apps were tuned towards amplifying bodily sound (e.g. breath, voice), however participants were also very interested in using the parabola itself to generate sound, as if it was an instrument, by striking, tapping and plucking it, creating a need for the parabola to speak back.

Finally, we acknowledge that the majority of participants had musical experience; we are also interested for future studies to include more non-musicians.

## 5. SUMMARY AND FUTURE WORK

We have presented an audience experience study of a sound art installation environment whose design was aimed at promoting collective musical play and expression between audience members, and within an environment whose acoustics were altered by both physical objects and an audio AR system.

Returning to our core research questions - *how can audio augmented reality enable collective musical expression?* - we were not expecting to find definitive outputs with this formative study, only to shed light on the research areas and support future directions in the development of the installation. We successfully promoted collective playfulness and experimentation with sound through digitally mediated audio perception, in the augmentation of both virtual and real environments and the audience's listening perception. For example, it is possible to recompose an environment as a musical instrument by changing sonic perception of it, while playfulness was enabled through a sense of safe immersion in both environments (e.g. the apps, collective audience experience), central to any mode of creativity.

The way in which audio AR draws sonic experience inwards, creates a dissonance in the design of collective experience with this technology. It alters a fundamental norm of musical instruments that they can be used to perform to others. In the case of audio AR, the player is experiencing their own personal transformation of the sound-world around them. However, in contrast to this, AR can also promote collective creative experience by extending the scope of what is playable, by extending that personal space with altered or heightened sound perception and disrupting the natural hierarchy of a sound environment by, for example, prioritising bodily sounds. When a sound installation environment itself becomes more instrument-like then it can become a collective instrument and consequently a shared channel of communication between audience members in the AR world, despite the personal or even intimate nature of their experience.

In response to the study and considering future development of this installation, it is clear that the AR apps can stand alone as mediators of new sonic experiences. However, in making the personal experience of AR into an interpersonal experience - central to collective musical expression, it is key to think further about how to network and merge the real and virtual environments. It is also necessary to question how to create a balance of interplay between audience and composed environments for creative expression, real and virtual, and how to reduce social inhibition in the installation environment for it to become instrument.

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